ARMY RESEARCH LABORATORY

The Lightweight Artillery Projectile

by James M. Bender

ARL-TR-2573 September 2001

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ARL-TR-2573 **September 2001**

The Lightweight Artillery Projectile

James M. Bender
Weapons and Materials Research Directorate, ARL

Abstract

This report discusses the logistical advantages of using composite materials as a substitute for steel in 155-mm cargo-carrying artillery shells. A weight savings of 25–30% per projectile can be realized. Combined with the weight savings offered by the XM777 lightweight howitzer, Light and Rapid Deployment Forces can be equipped with the firepower of the 155-mm cannon utilizing projectiles with a four-to-one lethality advantage over their 105-mm counterpart, while weighing approximately twice as much. The system of lightweight howitzers and projectiles offers these forces a substantial increase in lethality as measured by kills per logistical ton.

Acknowledgments

Mr. Robert Kaste and Mr. James Garner performed extensive analysis and design work on the fin assembly of the subject projectile. Their efforts were key to the success of the prototype. Mr. David Spagnuolo is hereby commended for his excellent fabrication of the composite shell resulting in a first-time success. Mr. Peter Dehmer's and Ms. Melissa Klusewitz's work on the fin protector cup was exemplary and resulted in a potentially patentable item. Lastly, Mr. Gary Sprenkle's work manufacturing the fin assembly was up to his usual standard of excellence.

INTENTIONALLY LEFT BLANK.

Contents

INTENTIONALLY LEFT BLANK.

List of Figures

List of Tables

INTENTIONALLY LEFT BLANK.

1. Introduction

Cannon-launched artillery projectiles have a long history of being made chiefly of steel and containing varying amounts of explosive for blast and fragmentation effects. Steel shells ranging from 40 to 240 mm dominated the battlefield in World War I (WWI) and World War II (WWII) with some carrying cargo other than high explosives, i.e., smoke and gas agents. Just before and during the Vietnam War, cargo-carrying artillery shells that carried small grenades were developed and increased the lethality of shells significantly when brought to bear on certain targets. With this modernization came a logistical penalty in the form of increased weight. The M198 towed howitzer weighs in at 15,800 lb (7,182 kg) with shells weighing nominally 100 lb (45 kg). Modern warfare has, through the necessity to rapidly emplace firepower, given birth to Rapid Deployment and Special Forces that require lightweight, air-transportable and mass-efficient weapons, resulting in higher lethality per logistical ton. These forces carry the name "Light," and must be capable of projecting lethal fires with minimal logistical burden within 18 hr virtually anywhere in the world. Large prime movers are not among their assets and they must compete for heavy lift aircraft when deploying. Thus, light forces are constrained by weight yet must be rapidly deployed and highly lethal.

Modern composite materials are being exploited to fill many roles in the U.S. Army initiative to "Lighten the Force." They can be found in weapons such as sabots, armor, vehicle structures, and transport containers, to name a few. State-of-the-art analysis and cutting edge manufacturing processes have given rise to high-strength composite materials that are unidirectionally as strong as steel in a particular application, yet weigh 1/5 as much per unit volume. The High Capacity Artillery Projectile (HICAP) program was the first of its kind to employ off-the-shelf carbon/epoxy composite materials for fabrication of artillery shells. The prototypes had to withstand over 13,000 g's of axial acceleration and be compatible with the highest charge in the 155-mm system. The technology from that program has been used extensively by the Navy (Best Buy program) and by the Army in the current lightweight artillery shell effort, the "75-lb shell" which delivers submunitions.

Much attention has been focused on reducing the weight of the launcher as evidenced by the 40% reduction in weight from the M198 towed howitzer to that of the XM777 system described in the next section. However, the projectiles make up the largest part of the logistical burden and their weight alone dismisses them from consideration for use in Light Forces application even though a 155-mm shell can carry proportionally more payload by weight (3.5 times per round) and has greater range. The 75-lb shell, on the other hand, can carry even

more payload than the M483 made possible by the reduced thickness of the shell. The inside diameter of the M483 is 5 in (127 mm) compared to 5.5 in (139 mm) for the 75-lb shell. This provides approximately 24 in^3 (387 cm^3) more payload volume. Thus, the 75-lb shell can carry four times as many M80 grenades than the new XM915/916 105-mm projectile while weighing only twice as much. This significantly increases mass efficiency and reduces crew fatigue in comparison to current 155-mm steel shells.

2. "Lighten the Force" Initiative Applied to Artillery

Two grenade-carrying artillery shells currently in the 155-mm inventory are the M483A1 and the M864, both 155 mm—the latter being a base-burn assisted, longer range, slightly less lethal version of the former since 16 grenades are removed to accommodate the base-burn module. Each delivers a payload of M42/M46 grenades and disseminates them over the target area. A similar 105-mm version is the XM915 which carries the new M80 grenade—a smaller version of its predecessor, the M42, with the comparable antiarmor capability and a new self-destruct fuze. Grenades are many times more effective as a distributed group at defeating certain enemy targets than single-point high-explosive rounds like the M107. This type of round is highly desired by Light Forces, which currently employ 105-mm howitzers for the direct support mission.

The U.S. Army and the United Kingdom are developing a lightweight towed 155-mm platform, the XM777 (Figure 1), which will weigh 40% less than the M198 towed howitzer. This weapon will be capable of firing all current projectiles in the 155-mm inventory and their propelling charges. Still, it weighs more than twice as much as the 105-mm howitzer with ammunition that weighs three times as much per shell, though each is substantially more lethal than a 105-mm shell. Light and Rapid Deployment Forces must consider a choice: heavier and lethal (155 mm) or lighter and substantially less lethal per round (105 mm). Whether the Light Forces will use the new 155-mm system or retain the 105-mm system or both is beyond the scope of this report.

Table 1 illustrates the difference between a 155-mm lightweight shell and a comparable 105-mm shell. They are compared in two ways: by projectile and by mass efficiency. A current 155-mm steel cargo shell, the M483A1, is included for reference.

Figure 1. The XM777 155-mm lightweight towed howitzer.

Table 1. Comparison of artillery system mass efficiency.

Caliber (mm)	Projectile	Cargo Mass (lb/kg)	Non-Cargo Mass (lb/kg)	Total Mass (Projectile + Propulsion Charge) (lb/kg)	Mass of Cargo/ Total Mass of Projectile (Mass Efficiency)
105	XM915	12.0/5.5	32.0/14.5	44.0/20.0	0.27
155	75-lb shell	48.0/21.8	50.0/22.7	98.0/44.5	0.49
155	M483A1	40.0/18.4	92.0/41.8	132.00/60.0	0.30

The table illustrates that the logistical burden is drastically reduced, mostly due to the reduction of parasitic mass—the amount of non-cargo mass that inflicts no damage. The expected fractional damage per logistical ton is nearly doubled, due to the use of composite materials in the shell. This claim assumes that the grenade density on the ground is the same for each round. Another viewpoint would be that the forces have the same number of stowed kills onboard transportation assets at approximately half the current weight. As for the advantages of composite materials in place of steel in a 155-mm system, a 26% weight savings is realized, since the cargo would be the same.

3. Emerging Technology

The next generation of a lightweight artillery platform is the Future Combat System (FCS). The caliber of that system is still undergoing study, however, it will exploit lightweight materials. The technology being addressed under this program is being investigated in a 155-mm platform to be compatible with the XM777, but also applicable to other calibers that may be selected in future cannon programs. Cargo-carrying artillery shells have historically been fabricated from steel for two reasons: (1) the obvious structural requirements to sustain the setback loads from launch and, (2) the need for mass at the outer radius of the shell for spin stabilization. A composite artillery shell (Figure 2) weighs substantially less than its steel counterpart allowing an equal payload to that of steel shells at a 25-30% overall weight reduction. They do not have enough mass at the outer radius for spin stabilization and therefore require deployable fins for stability. Composite deployable fins were demonstrated with the HICAP program in June 1996 [1]. Also, a 1/4-in (6-mm)-thick composite shell was demonstrated on the same test with the top-zone (8-S) charge. In 1992, Lyle Kayser of the U.S. Army Ballistic Research Laboratory (BRL) developed a new approach to fin stabilization through a design that orients the fin's longest dimension with the air stream as an improvement over the original HICAP fin assembly. A novel design approach featuring deployable fins with an elliptical leading edge incorporated into the design resulted in lower drag with sufficient surface area for stabilization [2]. These new fins are illustrated in Figure 2 and prototypes with more detail are shown in Figures 3 and 4. A significant amount of the loss of ballistic coefficient* can likely be recaptured. However, the fin assembly intrudes into the chamber further than the M549 projectile, which has the longest boattail of all the rounds in the current inventory. The chamber intrusion would not allow the use of the M203A1 charge in the current 155-mm howitzer due to interference. The M119A2 (zone 7, red bag) charge would allow enough space for the long boattail. A systems approach is necessary so that the chamber of a new howitzer is designed to accommodate long boattailed rounds.

* Ballistic coefficient is a ration of mass-to-projectile diameter. Reducing the mass of a projectile while maintaining the diameter reduces the ballistic coefficient making it more susceptible to drag.

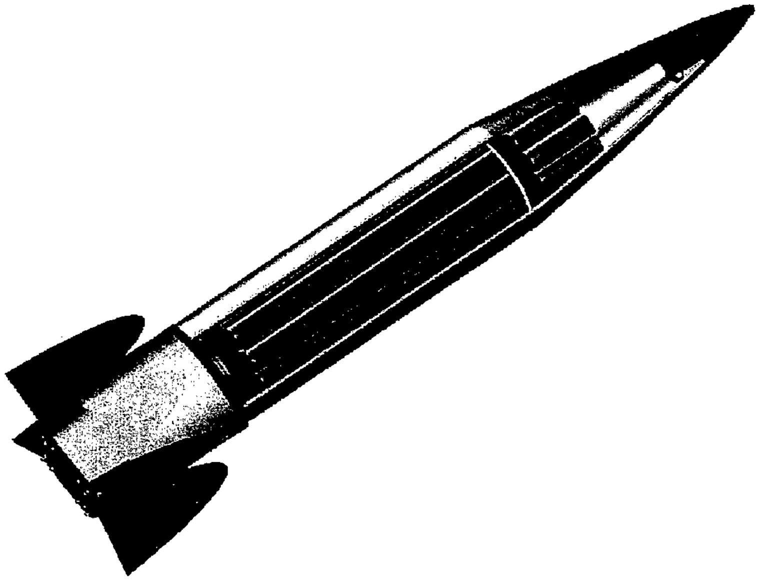

Figure 2. The lightweight 155-mm cargo-carrying projectile.

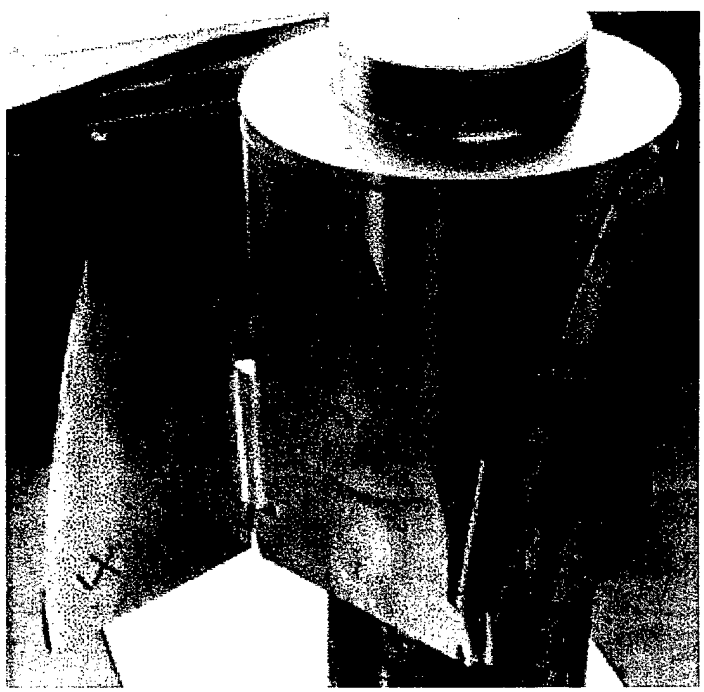

Figure 3. Kayser fin deploying.

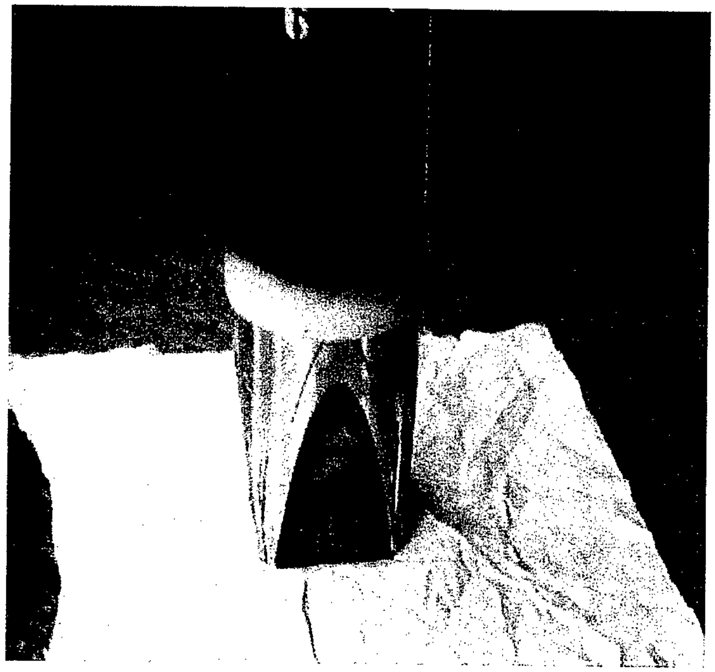

Figure 4. Kayser fins before adding fin protector cup.

The Kayser fin was modeled using ANSYS to determine the strength of design in the blast region. When the fins are in the open position and being introduced to the air stream transitioning from the blast region, they are exposed to approximately 15 psi. Given the 2° angle of attack, the estimated pressure vector normal to the fin was 15 psi (103 kPa). The results of that analysis are shown in Figure 5. The fin assembly was tested at the U.S. Army's Transonic Range Facility at ARL. The assembly was attached to a simulated projectile mass, commonly called a "slug." The total weight of the test projectile was 75 lb (34 kg). A zone 7 (red bag) charge was used to propel the projectile to a muzzle velocity of approximately 2,015 ft/s (614 m/s). Peak chamber pressure generated was approximately 40 kpsi (276 MPa). Shown in Figure 6 is a high-speed smear photograph taken at 25 ft (7.6 m) from the muzzle.

4. Technology From the HICAP Program

The HICAP program was a successful Army Science and Technology Objective (STO) and an applied research joint effort with the U.S. Armament Research and Development Center (ARDEC) from 1991 to 1996. It was the first artillery program to prove the launch structural integrity of very long (74 in [188 cm]) polymer composite artillery shells, with deployable fins and snap joint

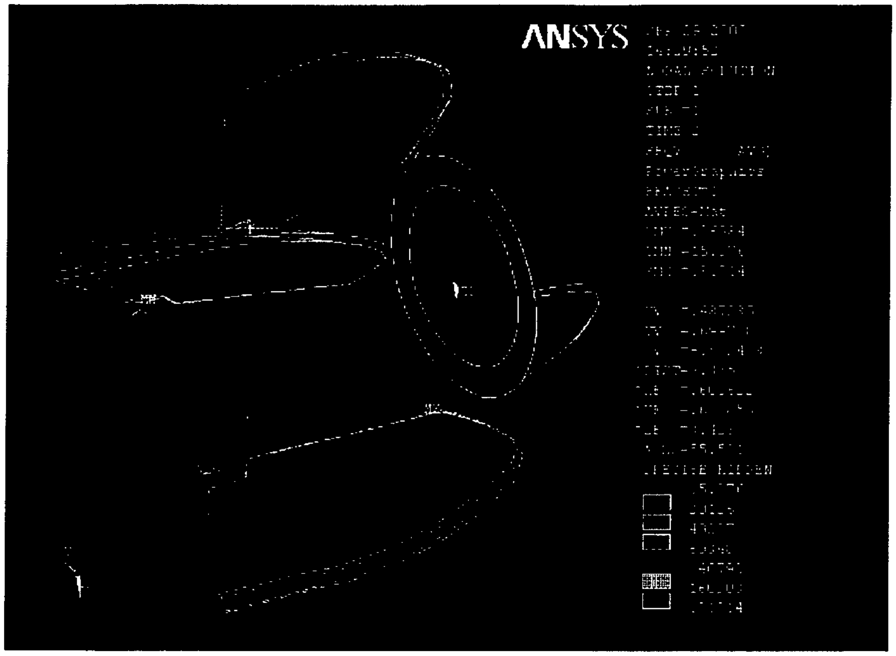

Figure 5. Stress on fin due to aerodynamic loads.

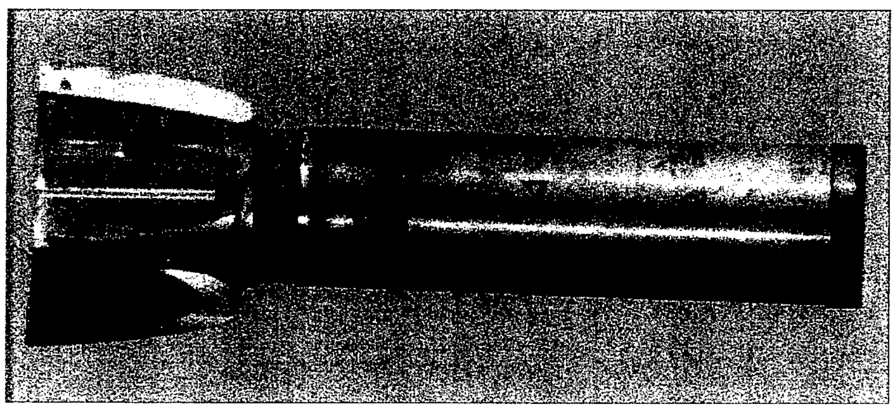

Figure 6. Pre-test of Kayser fin assembly.

construction. The HICAP is shown in Figure 7. In October 1995, the HICAP was proven structurally sound with the M203A1 charge in a launch integrity test at the ARL's Transonic Range. Figure 8 is a muzzle exit high-speed photograph of the prototype HICAP. In June 1996, five HICAP projectiles were flown to full range using the M203A1 charge, completing the demonstration program. The grenade-dispense system had been tested prior to full-range flight tests. When over the target area, the rear section dispenses similarly to the M483A1 by ejecting the grenades through the base. The forward shell is pressurized and bursts so the grenades are dispersed at various radial velocities and fall to the

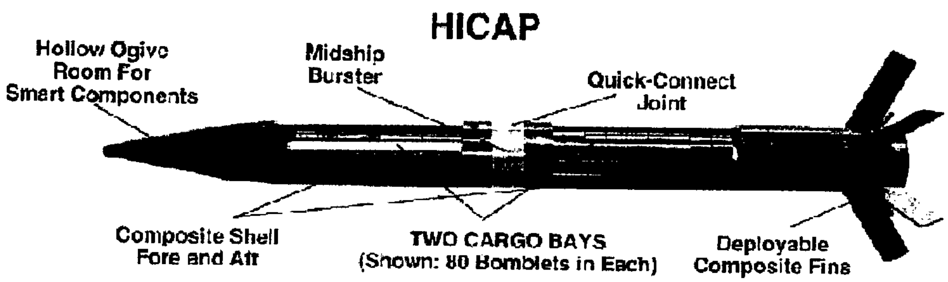

Figure 7. The HICAP.

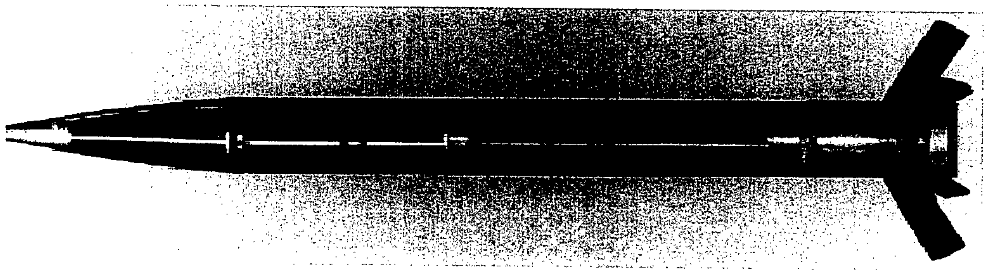

Figure 8. Muzzle exit high-speed photograph of HICAP.

ground. Figure 9 shows the results of a laboratory burst test with M42 grenades as payload. The radial expulsion velocity of the grenades was optically measured and averaged at 200 ft/s (61 m/s), considered favorable for an acceptable density on the ground to achieve the desired fractional damage. Many technologies from HICAP can be applied to a unitary lightweight shell for the Light Forces. In the present effort, the forward shell from HICAP was used. It is fabricated using carbon-epoxy material and is only 0.25 in (6 mm), and thereby maximizes payload volume when compared to the M483A1 in which the shell is 0.5 in (13 mm) thick. It must sustain only its own weight plus a fuze and expulsion charge. The method of attachment to the base and the expulsion system were also adapted from the HICAP program. However, the 75-lb shell will use the new M80 grenade and therefore more of them can be placed in the shell due to their smaller diameter.

5. Prototype Testing

The first prototype testing of the lightweight artillery shell was performed at ARL's Transonic Range in April 2000. The fin assembly, aeroshell, fin protector cup and all related hardware were manufactured at ARL. The payload of 168 M80 grenades was simulated by an equivalent mass of aluminum. The projectile is shown in Figure 10, broken down by components for clarity. The fin protector

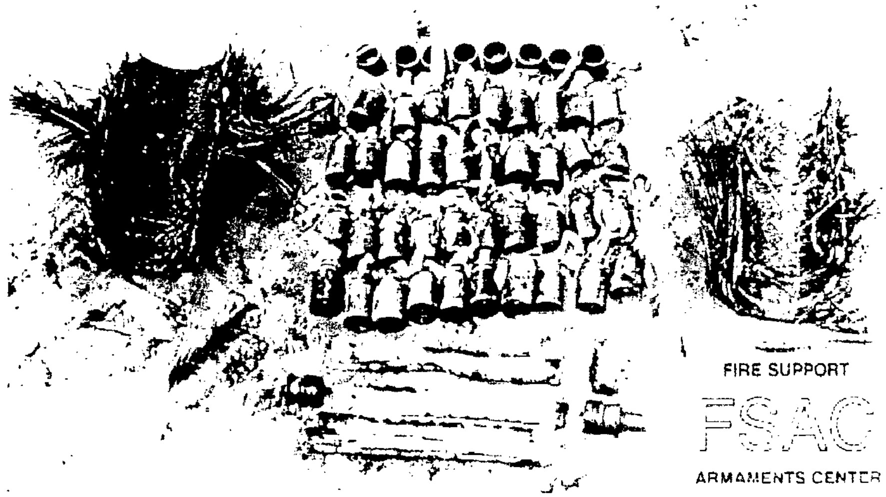

Figure 9. Result of grenade-dispense burst of forward shell.

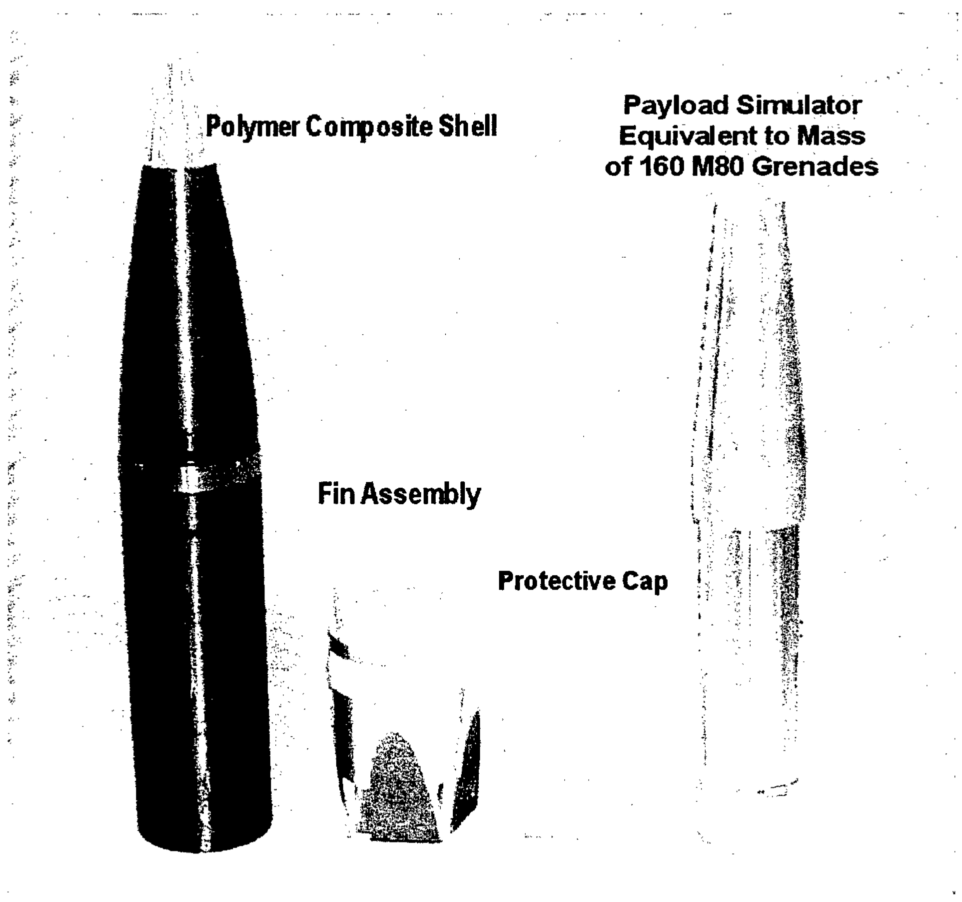

Figure 10. Lightweight artillery shell prototype before assembly.

cup is made from S-glass weave and an epoxy resin. Its function is to seal the fin assembly from gun gasses during launch, then shatter at muzzle exit allowing the fins to deploy. It is relatively flexible to allow it to conform to the shape of the fin assembly under pressure. The voids existing under the cup at the fin hinges are filled with a silicone gel. Under pressure, the gel responds hydrostatically to oppose the pressure from the gun gasses, preventing gas jetting and damage.

This projectile's fin assembly is relatively long (but not necessarily so) and renders it incompatible with the zone 8S charge due to interference. However, sufficient muzzle velocity is achieved with the zone 7 charge since the projectile is so much lighter. Figure 11 is a high-speed photo of the projectile just after muzzle exit. Two of the four fins have locked in place. The other two have not fully deployed and locked. It has been determined that these fins may have been pushed back to the folded position due to initial yaw of the projectile. The forces from airflow on these two fins would tend to close them back up before locking. It was also determined that the spring stiffness on the locking pin was insufficient to force the pin into place quickly enough.

6. Recommendations

In an effort to assure full fin deployment, two modifications will be incorporated into the design. First, the slip obturator will be modified to slightly increase the initial spin rate. This would impart more angular momentum to the fins and deploy them more quickly. It would also alleviate some of the initial yaw observed in Figure 11. Second, a locking pin with a much higher spring constant will replace the current one. The high-speed down-bore movies indicated that the fins fully opened but did not lock. Employing a stiffer spring will help ensure the fins lock in place quicker. The current design uses a spring with a constant of less than 1 lb/in (1.8 N/cm). The new locking pin spring constant is 52 lb/in (91.8 kg/cm).

Figure 11. Muzzle exit photograph of the lightweight artillery projectile.

The current base (fin housing) is fabricated from high-strength aluminum that is hollowed out to reduce mass. A study is currently underway to investigate the use of composite materials for the base. This would remove sufficient mass to allow the addition of a rocket motor for increased range without a weight penalty or reducing the payload. One challenge of using polymer composites is the very high and localized stresses generated when deploying fins are stopped suddenly as they lock into position. This may shear the composite at the point of attachment of the hinge pin. A metal plate will be added onto the bottom as shown in Figure 12 (dark red) to mitigate this problem and serve as a more solid point of attachment for the hinge pins. Additional support rods would run the length of the structure and attach to a threaded metal ring at the top for ease of attachment to the shell adapter, which is a double-male threaded metallic ring.

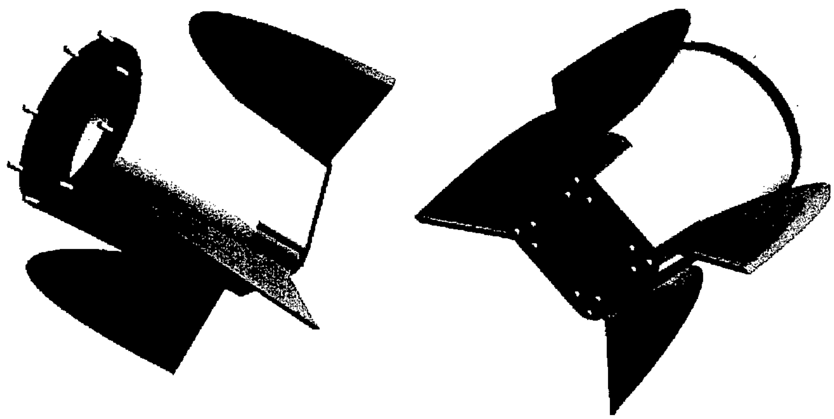

Figure 12. Composite material version of Kayser fin assembly.

7. Conclusions

The reduction of aerodynamic drag to increase range by the use of Kayser fins is a critical technology for a lightweight artillery shell. The technology has been proven using aluminum and further investigations into the use of composite materials are planned. The weapon platform is only part of the logistical equation in an effort to "Lighten the Force." Ammunition that is equal in lethality and range and weighs 25% less than current ammunition reduces the logistical burden without reducing effectiveness. Simply, this means that the Light Forces can emplace more firepower per logistical ton.

INTENTIONALLY LEFT BLANK.

8. References

1. Burns, B. P., and J. M. Bender. "High Capacity Artillery Projectile (HICAP) Executive Summary." ARL-TR-1755, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, August 1998.

2. Kayser, L. "Aerodynamics of Fin-Stabilized Projectiles at Moderate Spin Rates." BRL-MR-3965, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, June 1992.

INTENTIONALLY LEFT BLANK.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197
	ABERDEEN PROVING GROUND
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CP CA D SNIDER 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TA 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TL 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR DA OASARDA SARD SO 103 ARMY PENTAGON WASHINGTON DC 20310-0103
1	DPTY ASST SECY FOR R&T SARD TT THE PENTAGON RM 3EA79 WASHINGTON DC 20301-7100
1	COMMANDER US ARMY MATERIEL CMD AMXMI INT 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
4	COMMANDER US ARMY ARDEC AMSTA AR CC G PAYNE J GEHBAUER C BAULIEU H OPAT PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY ARDEC AMSTA AR AE WW E BAKER J PEARSON PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR TD C SPINELLI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSE PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCH A W ANDREWS S MUSALLI R CARR M LUCIANO E LOGSDEN T LOUZEIRO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR CCH P J LUTZ PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSF T C LIVECCHIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA ASF PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T C C PATEL PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR M D DEMELLA PICATINNY ARSENAL NJ 07806-5000
3	COMMANDER US ARMY ARDEC AMSTA AR FSA A WARNASH B MACHAK M CHIEFA PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR FSP G M SCHIKSNIS D CARLUCCI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSP A P KISATSKY PICATINNY ARSENAL NJ 07806-5000
2	COMMANDER US ARMY ARDEC AMSTA AR CCH C H CHANIN S CHICO PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR QAC T D RIGOGLIOSO PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY ARDEC AMSTA AR WET T SACHAR BLDG 172 PICATINNY ARSENAL NJ 07806-5000
9	COMMANDER US ARMY ARDEC AMSTA AR CCH B P DONADIA F DONLON P VALENTI C KNUTSON G EUSTICE S PATEL G WAGNECZ R SAYER F CHANG PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCL F PUZYCKI R MCHUGH D CONWAY E JAROSZEWSKI R SCHLENNER M CLUNE PICATINNY ARSENAL NJ 07806-5000
5	PM SADARM SFAE GCSS SD COL B ELLIS M DEVINE W DEMASSI J PRITCHARD S HROWNAK PICATINNY ARSENAL NJ 07806-5000
1	US ARMY ARDEC INTELLIGENCE SPECIALIST AMSTA AR WEL F M GUERRIERE PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
2	PEO FIELD ARTILLERY SYS SFAE FAS PM H GOLDMAN T MCWILLIAMS PICATINNY ARSENAL NJ 07806-5000
12	PM TMAS SFAE GSSC TMA R MORRIS C KIMKER D GUZIEWICZ E KOPACZ R ROESER R DARCY R KOWALSKI R MCDANOLDS L D ULISSE C ROLLER J MCGREEN B PATTER PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR WEA J BRESCIA PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC PRODUCTION BASE MODERN ACTY AMSMC PBM K PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY TACOM PM ABRAMS SFAE ASM AB 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM AMSTA SF WARREN MI 48397-5000

NO. OF COPIES	ORGANIZATION
3	COMMANDER US ARMY TACOM PM TACTICAL VEHICLES SFAE TVL SFAE TVM SFAE TVH 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM BFVS SFAE ASM BV 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM AFAS SFAE ASM AF 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM RDT&E SFAE GCSS W AB J GODELL 6501 ELEVEN MILE RD WARREN MI 48397-5000
2	COMMANDER US ARMY TACOM PM SURV SYS SFAE ASM SS T DEAN SFAE GCSS W GSI M D COCHRAN 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	US ARMY CERL R LAMPO 2902 NEWMARK DR CHAMPAIGN IL 61822

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY TACOM PM SURVIVABLE SYSTEMS SFAE GCSS W GSI H M RYZYI 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM PM BFV SFAE GCSS W BV S DAVIS 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER US ARMY TACOM CHIEF ABRAMS TESTING SFAE GCSS W AB QT T KRASKIEWICZ 6501 ELEVEN MILE RD WARREN MI 48397-5000
1	COMMANDER WATERVLIET ARSENAL SMCWV QAE Q B VANINA BLDG 44 WATERVLIET NY 12189-4050
2	TSM ABRAMS ATZK TS S JABURG W MEINSHAUSEN FT KNOX KY 40121
3	ARMOR SCHOOL ATZK TD R BAUEN J BERG A POMEY FT KNOX KY 40121

NO. OF COPIES	ORGANIZATION
14	COMMANDER US ARMY TACOM AMSTA TR R R MCCLELLAND D THOMAS J BENNETT D HANSEN AMSTA JSK S GOODMAN J FLORENCE K IYER D TEMPLETON A SCHUMACHER AMSTA TR D D OSTBERG L HINOJOSA B RAJU AMSTA CS SF H HUTCHINSON F SCHWARZ WARREN MI 48397-5000
14	BENET LABORATORIES AMSTA AR CCB R FISCELLA M SOJA E KATHE M SCAVULO G SPENCER P WHEELER S KRUPSKI J VASILAKIS G FRIAR R HASENBEIN AMSTA CCB R S SOPOK E HYLAND D CRAYON R DILLON WATERVLIET NY 12189-4050
2	HQ IOC TANK AMMUNITION TEAM AMSIO SMT R CRAWFORD W HARRIS ROCK ISLAND IL 61299-6000

NO. OF COPIES	ORGANIZATION
2	COMMANDER US ARMY AMCOM AVIATION APPLIED TECH DIR J SCHUCK FT EUSTIS VA 23604-5577
1	DIRECTOR US ARMY AMCOM SFAE AV RAM TV D CALDWELL BLDG 5300 REDSTONE ARSENAL AL 35898
2	US ARMY CORPS OF ENGINEERS CERD C T LIU CEW ET T TAN 20 MASS AVE NW WASHINGTON DC 20314
1	US ARMY COLD REGIONS RSCH & ENGRNG LAB P DUTTA 72 LYME RD HANOVER NH 03755
1	SYSTEM MANAGER ABRAMS ATZK TS LTC J H NUNN BLDG 1002 RM 110 FT KNOX KY 40121
1	USA SBCCOM PM SOLDIER SPT AMSSB PM RSS A J CONNORS KANSAS ST NATICK MA 01760-5057
2	USA SBCCOM MATERIAL SCIENCE TEAM AMSSB RSS J HERBERT M SENNETT KANSAS ST NATICK MA 01760-5057

NO. OF COPIES	ORGANIZATION
2	OFC OF NAVAL RESEARCH D SIEGEL CODE 351 J KELLY 800 N QUINCY ST ARLINGTON VA 22217-5660
1	NAVAL SURFACE WARFARE CTR DAHLGREN DIV CODE G06 DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR TECH LIBRARY CODE 323 17320 DAHLGREN RD DAHLGREN VA 22448
1	NAVAL SURFACE WARFARE CTR CRANE DIVISION M JOHNSON CODE 20H4 LOUISVILLE KY 40214-5245
8	DIRECTOR US ARMY NATIONAL GROUND INTELLIGENCE CTR D LEITER M HOLTUS M WOLFE S MINGLEDORF J GASTON W GSTATTENBAUER R WARNER J CRIDER 220 SEVENTH ST NE CHARLOTTESVILLE VA 22091
2	NAVAL SURFACE WARFARE CTR U SORATHIA C WILLIAMS CD 6551 9500 MACARTHUR BLVD WEST BETHESDA MD 20817
2	COMMANDER NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R PETERSON CODE 2020 M CRITCHFIELD CODE 1730 BETHESDA MD 20084

NO. OF COPIES	ORGANIZATION
8	US ARMY SBCCOM SOLDIER SYSTEMS CENTER BALLISTICS TEAM J WARD W ZUKAS P CUNNIFF J SONG MARINE CORPS TEAM J MACKIEWICZ BUS AREA ADVOCACY TEAM W HASKELL AMSSB RCP SS W NYKVIST S BEAUDOIN KANSAS ST NATICK MA 01760-5019
9	US ARMY RESEARCH OFC A CROWSON J CHANDRA H EVERETT J PRATER R SINGLETON G ANDERSON D STEPP D KISEROW J CHANG PO BOX 12211 RESEARCH TRIANGLE PARK NC 27709-2211
8	NAVAL SURFACE WARFARE CTR J FRANCIS CODE G30 D WILSON CODE G32 R D COOPER CODE G32 J FRAYSSE CODE G33 E ROWE CODE G33 T DURAN CODE G33 L DE SIMONE CODE G33 R HUBBARD CODE G33 DAHLGREN VA 22448
1	NAVAL SEA SYSTEMS CMD D LIESE 2531 JEFFERSON DAVIS HWY ARLINGTON VA 22242-5160
1	NAVAL SURFACE WARFARE CTR M LACY CODE B02 17320 DAHLGREN RD DAHLGREN VA 22448

NO. OF COPIES	ORGANIZATION
2	NAVAL SURFACE WARFARE CTR CARDEROCK DIVISION R CRANE CODE 2802 C WILLIAMS CODE 6553 3A LEGGETT CIR BETHESDA MD 20054-5000
1	EXPEDITIONARY WARFARE DIV N85 F SHOUP 2000 NAVY PENTAGON WASHINGTON DC 20350-2000
1	AFRL MLBC 2941 P ST RM 136 WRIGHT PATTERSON AFB OH 45433-7750
1	AFRL MLSS R THOMSON 2179 12TH ST RM 122 WRIGHT PATTERSON AFB OH 45433-7718
2	AFRL F ABRAMS J BROWN BLDG 653 2977 P ST STE 6 WRIGHT PATTERSON AFB OH 45433-7739
1	WATERWAYS EXPERIMENT D SCOTT 3909 HALLS FERRY RD SC C VICKSBURG MS 39180
5	DIRECTOR LLNL R CHRISTENSEN S DETERESA F MAGNESS M FINGER MS 313 M MURPHY L 282 PO BOX 808 LIVERMORE CA 94550
1	AFRL MLS OL L COULTER 7278 4TH ST BLDG 100 BAY D HILL AFB UT 84056-5205

NO. OF COPIES	ORGANIZATION
1	OSD JOINT CCD TEST FORCE OSD JCCD R WILLIAMS 3909 HALLS FERRY RD VICKSBURG MS 29180-6199
1	DEFENSE NUCLEAR AGENCY INNOVATIVE CONCEPTS DIV 6801 TELEGRAPH RD ALEXANDRIA VA 22310-3398
3	DARPA M VANFOSSEN S WAX L CHRISTODOULOU 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
2	SERDP PROGRAM OFC PM P2 C PELLERIN B SMITH 901 N STUART ST STE 303 ARLINGTON VA 22203
1	FAA MIL HDBK 17 CHAIR L ILCEWICZ 1601 LIND AVE SW ANM 115N RESTON VA 98055
1	US DEPT OF ENERGY OFC OF ENVIRONMENTAL MANAGEMENT P RITZCOVAN 19901 GERMANTOWN RD GERMANTOWN MD 20874-1928
1	DIRECTOR LLNL F ADDESSIO MS B216 PO BOX 1633 LOS ALAMOS NM 87545
1	OAK RIDGE NATIONAL LABORATORY R M DAVIS PO BOX 2008 OAK RIDGE TN 37831-6195

NO. OF COPIES	ORGANIZATION
3	DIRECTOR SANDIA NATIONAL LABS APPLIED MECHANICS DEPT MS 9042 J HANDROCK Y R KAN J LAUFFER PO BOX 969 LIVERMORE CA 94551-0969
1	OAK RIDGE NATIONAL LABORATORY C EBERLE MS 8048 PO BOX 2008 OAK RIDGE TN 37831
1	OAK RIDGE NATIONAL LABORATORY C D WARREN MS 8039 PO BOX 2008 OAK RIDGE TN 37831
5	NIST J DUNKERS M VANLANDINGHAM MS 8621 J CHIN MS 8621 J MARTIN MS 8621 D DUTHINH MS 8611 100 BUREAU DR GAITHERSBURG MD 20899
1	HYDROGEOLOGIC INC SERDP ESTCP SPT OFC S WALSH 1155 HERNDON PKWY STE 900 HERNDON VA 20170
3	NASA LANGLEY RSCH CTR AMSRL VS W ELBER MS 266 F BARTLETT JR MS 266 G FARLEY MS 266 HAMPTON VA 23681-0001
1	NASA LANGLEY RSCH CTR T GATES MS 188E HAMPTON VA 23661-3400
1	FHWA E MUNLEY 6300 GEORGETOWN PIKE MCLEAN VA 22101

NO. OF COPIES	ORGANIZATION
3	CYTEC FIBERITE R DUNNE D KOHLI R MAYHEW 1300 REVOLUTION ST HAVRE DE GRACE MD 21078
1	USDOT FEDERAL RAILRD M FATEH RDV 31 WASHINGTON DC 20590
1	MARINE CORPS INTLLGNC ACTVTY D KOSITZKE 3300 RUSSELL RD STE 250 QUANTICO VA 22134-5011
1	DIRECTOR NATIONAL GRND INTLLGNC CTR IANG TMT 220 SEVENTH ST NE CHARLOTTESVILLE VA 22902-5396
1	SIOUX MFG B KRIEL PO BOX 400 FT TOTTEN ND 58335
2	3TEX CORPORATION A BOGDANOVICH J SINGLETARY 109 MACKENAN DR CARY NC 27511
1	3M CORPORATION J SKILDUM 3M CENTER BLDG 60 IN 01 ST PAUL MN 55144-1000
1	DIRECTOR DEFENSE INTLLGNC AGNCY TA 5 K CRELLING WASHINGTON DC 20310
1	ADVANCED GLASS FIBER YARNS T COLLINS 281 SPRING RUN LANE STE A DOWNINGTON PA 19335

NO. OF COPIES	ORGANIZATION
1	COMPOSITE MATERIALS INC D SHORTT 19105 63 AVE NE PO BOX 25 ARLINGTON WA 98223
1	JPS GLASS L CARTER PO BOX 260 SLATER RD SLATER SC 29683
1	COMPOSITE MATERIALS INC R HOLLAND 11 JEWEL CT ORINDA CA 94563
1	COMPOSITE MATERIALS INC C RILEY 14530 S ANSON AVE SANTA FE SPRINGS CA 90670
2	SIMULA J COLTMAN R HUYETT 10016 S 51ST ST PHOENIX AZ 85044
2	PROTECTION MATERIALS INC M MILLER F CRILLEY 14000 NW 58 CT MIAMI LAKES FL 33014
2	FOSTER MILLER M ROYLANCE W ZUKAS 195 BEAR HILL RD WALTHAM MA 02354-1196
1	ROM DEVELOPMENT CORP R O MEARA 136 SWINEBURNE ROW BRICK MARKET PLACE NEWPORT RI 02840

NO. OF COPIES	ORGANIZATION
2	TEXTRON SYSTEMS T FOLTZ M TREASURE 1449 MIDDLESEX ST LOWELL MA 01851
1	O GARA HESS & EISENHARDT M GILLESPIE 9113 LESAINT DR FAIRFIELD OH 45014
2	MILLIKEN RSCH CORP H KUHN M MACLEOD PO BOX 1926 SPARTANBURG SC 29303
1	CONNEAUGHT INDUSTRIES INC J SANTOS PO BOX 1425 COVENTRY RI 02816
1	BATTELLE NATICK OPNS B HALPIN 209 W CENTRAL ST STE 302 NATICK MA 01760
1	ARMTEC DEFENSE PRODUCTS S DYER 85 901 AVE 53 PO BOX 848 COACHELLA CA 92236
1	NATIONAL COMPOSITE CENTER T CORDELL 2000 COMPOSITE DR KETTERING OH 45420
3	PACIFIC NORTHWEST LAB M SMITH G VAN ARSDALE R SHIPPELL PO BOX 999 RICHLAND WA 99352
2	AMOCO PERFORMANCE PRODUCTS M MICHNO JR J BANISAUKAS 4500 MCGINNIS FERRY RD ALPHARETTA GA 30202-3944

NO. OF COPIES	ORGANIZATION
8	ALLIANT TECHSYSTEMS INC C CANDLAND MN11 2830 C AAKHUS MN11 2830 B SEE MN11 2439 N VLAHAKUS MN11 2145 R DOHRN MN11 2830 S HAGLUND MN11 2439 M HISSONG MN11 2830 D KAMDAR MN11 2830 600 SECOND ST NE HOPKINS MN 55343-8367
1	SAIC M PALMER 1410 SPRING HILL RD STE 400 MS SH4 5 MCLEAN VA 22102
1	SAIC G CHRYSSOMALLIS 3800 W 80TH ST STE 1090 BLOOMINGTON MN 55431
1	AAI CORPORATION T G STASTNY PO BOX 126 HUNT VALLEY MD 21030-0126
1	APPLIED COMPOSITES W GRISCH 333 NORTH SIXTH ST ST CHARLES IL 60174
1	CUSTOM ANALYTICAL ENG SYS INC A ALEXANDER 13000 TENSOR LANE NE FLINTSTONE MD 21530
3	ALLIANT TECHSYSTEMS INC J CONDON E LYNAM J GERHARD WV01 16 STATE RT 956 PO BOX 210 ROCKET CENTER WV 26726-0210
1	OFC DEPUTY UNDER SEC DEFNS J THOMPSON 1745 JEFFERSON DAVIS HWY CRYSTAL SQ 4 STE 501 ARLINGTON VA 22202

NO. OF COPIES	ORGANIZATION
1	PROJECTILE TECHNOLOGY INC 515 GILES ST HAVRE DE GRACE MD 21078
5	AEROJET GEN CORP D PILLASCH T COULTER C FLYNN D RUBAREZUL M GREINER 1100 WEST HOLLYVALE ST AZUSA CA 91702-0296
3	HEXCEL INC R BOE PO BOX 18748 SALT LAKE CITY UT 84118
1	HERCULES INC HERCULES PLAZA WILMINGTON DE 19894
1	BRIGS COMPANY J BACKOFEN 2668 PETERBOROUGH ST HERNDON VA 22071-2443
1	ZERNOW TECHNICAL SERVICES L ZERNOW 425 W BONITA AVE STE 208 SAN DIMAS CA 91773
1	GENERAL DYNAMICS OTS L WHITMORE 10101 NINTH ST NORTH ST PETERSBURG FL 33702
3	GENERAL DYNAMICS OTS FLINCHBAUGH DIV E STEINER B STEWART T LYNCH PO BOX 127 RED LION PA 17356
1	GKN AEROSPACE D OLDS 15 STERLING DR WALLINGFORD CT 06492

NO. OF COPIES	ORGANIZATION
5	SIKORSKY AIRCRAFT G JACARUSO T CARSTENSAN B KAY S GARBO MS S330A J ADELMANN 6900 MAIN ST PO BOX 9729 STRATFORD CT 06497-9729
1	PRATT & WHITNEY C WATSON 400 MAIN ST MS 114 37 EAST HARTFORD CT 06108
1	AEROSPACE CORP G HAWKINS M4 945 2350 E EL SEGUNDO BLVD EL SEGUNDO CA 90245
2	CYTEC FIBERITE M LIN W WEB 1440 N KRAEMER BLVD ANAHEIM CA 92806
1	UDLP G THOMAS PO BOX 58123 SANTA CLARA CA 95052
2	UDLP R BARRETT MAIL DROP M53 V HORVATICH MAIL DROP M53 328 W BROKAW RD SANTA CLARA CA 95052-0359
3	UDLP GROUND SYSTEMS DIVISION M PEDRAZZI MAIL DROP N09 A LEE MAIL DROP N11 M MACLEAN MAIL DROP N06 1205 COLEMAN AVE SANTA CLARA CA 95052
4	UDLP R BRYNSVOLD P JANKE MS 170 4800 EAST RIVER RD MINNEAPOLIS MN 55421-1498

NO. OF COPIES	ORGANIZATION
1	UDLP D MARTIN PO BOX 359 SANTA CLARA CA 95052
2	BOEING DFNSE & SPACE GP W HAMMOND S 4X55 J RUSSELL S 4X55 PO BOX 3707 SEATTLE WA 98124-2207
2	BOEING ROTORCRAFT P MINGURT P HANDEL 800 B PUTNAM BLVD WALLINGFORD PA 19086
1	BOEING DOUGLAS PRODUCTS DIV L J HART SMITH 3855 LAKEWOOD BLVD D800 0019 LONG BEACH CA 90846-0001
1	LOCKHEED MARTIN SKUNK WORKS D FORTNEY 1011 LOCKHEED WAY PALMDALE CA 93599-2502
1	LOCKHEED MARTIN R FIELDS 1195 IRWIN CT WINTER SPRINGS FL 32708
1	MATERIALS SCIENCES CORP G FLANAGAN 500 OFC CENTER DR STE 250 FT WASHINGTON PA 19034
1	NORTHRUP GRUMMAN CORP ELECTRONIC SENSORS & SYSTEMS DIV E SCHOCH MS V 16 1745A W NURSERY RD LINTHICUM MD 21090
1	GDLS DIVISION D BARTLE PO BOX 1901 WARREN MI 48090
2	GDLS D REES M PASIK PO BOX 2074 WARREN MI 48090-2074
1	GDLS MUSKEGON OPERATIONS W SOMMERS JR 76 GETTY ST MUSKEGON MI 49442
1	GENERAL DYNAMICS AMPHIBIOUS SYS SURVIVABILITY LEAD G WALKER 991 ANNAPOLIS WAY WOODBRIDGE VA 22191
6	INST FOR ADVANCED TECH H FAIR I MCNAB P SULLIVAN S BLESS W REINECKE C PERSAD 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
2	CIVIL ENGR RSCH FOUNDATION PRESIDENT H BERNSTEIN R BELLE 1015 15TH ST NW STE 600 WASHINGTON DC 20005
1	ARROW TECH ASSO 1233 SHELBURNE RD STE D8 SOUTH BURLINGTON VT 05403-7700
1	R EICHELBERGER CONSULTANT 409 W CATHERINE ST BEL AIR MD 21014-3613

NO. OF COPIES	ORGANIZATION
1	UCLA MANE DEPT ENGR IV H T HAHN LOS ANGELES CA 90024-1597
2	UNIV OF DAYTON RESEARCH INST R Y KIM A K ROY 300 COLLEGE PARK AVE DAYTON OH 45469-0168
1	UMASS LOWELL PLASTICS DEPT N SCHOTT 1 UNIVERSITY AVE LOWELL MA 01854
1	IIT RESEARCH CENTER D ROSE 201 MILL ST ROME NY 13440-6916
1	GA TECH RSCH INST GA INST OF TCHNLGY P FRIEDERICH ATLANTA GA 30392
1	MICHIGAN ST UNIV MSM DEPT R AVERILL 3515 EB EAST LANSING MI 48824-1226
1	UNIV OF WYOMING D ADAMS PO BOX 3295 LARAMIE WY 82071
2	PENN STATE UNIV R MCNITT C BAKIS 212 EARTH ENGR SCIENCES BLDG UNIVERSITY PARK PA 16802
1	PENN STATE UNIV R S ENGEL 245 HAMMOND BLDG UNIVERSITY PARK PA 16801

NO. OF COPIES	ORGANIZATION
1	PURDUE UNIV SCHOOL OF AERO & ASTRO C T SUN W LAFAYETTE IN 47907-1282
1	STANFORD UNIV DEPT OF AERONAUTICS & AEROBALLISTICS S TSAI DURANT BLDG STANFORD CA 94305
1	UNIV OF MAIN ADV STR & COMP LAB R LOPEZ ANIDO 5793 AEWC BLDG ORONO ME 04469-5793
1	JOHNS HOPKINS UNIV APPLIED PHYSICS LAB P WIENHOLD 11100 JOHNS HOPKINS RD LAUREL MD 20723-6099
1	UNIV OF DAYTON J M WHITNEY COLLEGE PARK AVE DAYTON OH 45469-0240
5	UNIV OF DELAWARE CTR FOR COMPOSITE MTRLS J GILLESPIE M SANTARE S YARLAGADDA S ADVANI D HEIDER 201 SPENCER LABORATORY NEWARK DE 19716
1	DEPT OF MATERIALS SCIENCE & ENGINEERING UNIVERSITY OF ILLINOIS AT URBANA CHAMPAIGN J ECONOMY 1304 WEST GREEN ST 115B URBANA IL 61801

NO. OF COPIES	ORGANIZATION
1	NORTH CAROLINA STATE UNIV CIVIL ENGINEERING DEPT W RASDORF PO BOX 7908 RALEIGH NC 27696-7908
1	UNIV OF MARYLAND DEPT OF AEROSPACE ENGNRNG A J VIZZINI COLLEGE PARK MD 20742
3	UNIV OF TEXAS AT AUSTIN CTR FOR ELECTROMECHANICS J PRICE A WALLS J KITZMILLER 10100 BURNET RD AUSTIN TX 78758-4497
3	VA POLYTECHNICAL INST & STATE UNIV DEPT OF ESM M W HYER K REIFSNIDER R JONES BLACKSBURG VA 24061-0219
1	DREXEL UNIV A S D WANG 32ND & CHESTNUT ST PHILADELPHIA PA 19104
1	SOUTHWEST RSCH INST ENGR & MATL SCIENCES DIV J RIEGEL 6220 CULEBRA RD PO DRAWER 28510 SAN ANTONIO TX 78228-0510

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
1	US ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY P DIETZ 392 HOPKINS RD AMXSY TD APG MD 21005-5071
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP AP L APG MD 21005-5066

ABERDEEN PROVING GROUND (CONT)

NO. OF COPIES	ORGANIZATION
91	DIR USARL AMSRL CI AMSRL CI H W STUREK AMSRL CI S A MARK AMSRL CS IO FI M ADAMSON AMSRL SL BA AMSRL SL BL D BELY R HENRY AMSRL SL BG AMSRL SL I AMSRL WM J SMITH AMSRL WM B A HORST AMSRL WM BA D LYON AMSRL WM BC P PLOSTINS J NEWILL S WILKERSON A ZIELINSKI AMSRL WM BD B FORCH R FIFER R PESCE RODRIGUEZ B RICE AMSRL WM BE C LEVERITT AMSRL WM BF J LACETERA AMSRL WM BR C SHOEMAKER J BORNSTEIN AMSRL WM M D VIECHNICKI G HAGNAUER J MCCAULEY AMSRL WM MA L GHIORSE S MCKNIGHT AMSRL WM MB B FINK J BENDER T BOGETTI R BOSSOLI L BURTON

NO. OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

K BOYD
S CORNELISON
P DEHMER
R DOOLEY
W DRYSDALE
G GAZONAS
S GHIORSE
D GRANVILLE
D HOPKINS
C HOPPEL
D HENRY
R KASTE
M KLUSEWITZ
M LEADORE
R LIEB
E RIGAS
J SANDS
D SPAGNUOLO
W SPURGEON
J TZENG
E WETZEL
A FRYDMAN
AMRSL WM MC
J BEATTY
E CHIN
J MONTGOMERY
A WERECZCAK
J LASALVIA
J WELLS
AMSRL WM MD
W ROY
S WALSH
AMSRL WM T
B BURNS
M ZOLTOSKI
AMSRL WM TA
W GILLICH
T HAVEL
J RUNYEON
M BURKINS
E HORWATH
B GOOCH
W BRUCHEY
M NORMANDIA

NO. OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND (CONT)

AMRSL WM TB
D KOOKER
P BAKER
AMSRL WM TC
R COATES
AMSRL WM TD
A DAS GUPTA
T HADUCH
T MOYNIHAN
F GREGORY
M RAFTENBERG
M BOTELER
T WEERASOORIYA
D DANDEKAR
A DIETRICH
AMSRL WM TE
A NIILER
J POWELL
AMSRL SS SD
H WALLACE
AMSRL SS SE DS
R REYZER
R ATKINSON

NO. OF COPIES	ORGANIZATION
1	LTD R MARTIN MERL TAMWORTH RD HERTFORD SG13 7DG UK
1	SMC SCOTLAND P W LAY DERA ROSYTH ROSYTH ROYAL DOCKYARD DUNFERMLINE FIFE KY 11 2XR UK
1	CIVIL AVIATION ADMINSTRATION T GOTTESMAN PO BOX 8 BEN GURION INTERNL AIRPORT LOD 70150 ISRAEL
1	AEROSPATIALE S ANDRE A BTE CC RTE MD132 316 ROUTE DE BAYONNE TOULOUSE 31060 FRANCE
1	DRA FORT HALSTEAD P N JONES SEVEN OAKS KENT TN 147BP UK
1	DEFENSE RESEARCH ESTAB VALCARTIER F LESAGE COURCELETTE QUEBEC COA IRO CANADA
1	SWISS FEDERAL ARMAMENTS WKS W LANZ ALLMENDSTRASSE 86 3602 THUN SWITZERLAND
1	DYNAMEC RESEARCH AB AKE PERSSON BOX 201 SE 151 23 SODERTALJE SWEDEN

NO. OF COPIES	ORGANIZATION
1	ISRAEL INST OF TECHNOLOGY S BODNER FACULTY OF MECHANICAL ENGR HAIFA 3200 ISRAEL
1	DSTO MATERIALS RESEARCH LAB NAVAL PLATFORM VULNERABILITY SHIP STRUCTURES & MTRLS DIV N BURMAN PO BOX 50 ASCOT VALE VICTORIA AUSTRALIA 3032
1	ECOLE ROYAL MILITAIRE E CELENS AVE DE LA RENAISSANCE 30 1040 BRUXELLE BELGIQUE
1	DEF RES ESTABLISHMENT VALCARTIER A DUPUIS 2459 BOULEVARD PIE XI NORTH VALCARTIER QUEBEC CANADA PO BOX 8800 COURCELETTE GOA IRO QUEBEC CANADA
1	INSTITUT FRANCO ALLEMAND DE RECHERCHES DE SAINT LOUIS DE M GIRAUD 5 RUE DU GENERAL CASSAGNOU BOITE POSTALE 34 F 68301 SAINT LOUIS CEDEX FRANCE
1	ECOLE POLYTECH J MANSON DMX LTC CH 1015 LAUSANNE SWITZERLAND

NO. OF COPIES	ORGANIZATION
1	TNO PRINS MAURITS LABORATORY R IJSSELSTEIN LANGE KLEIWEG 137 PO BOX 45 2280 AA RIJSWIJK THE NETHERLANDS
2	FOA NATL DEFENSE RESEARCH ESTAB DIR DEPT OF WEAPONS & PROTECTION B JANZON R HOLMLIN S 172 90 STOCKHOLM SWEDEN
2	DEFENSE TECH & PROC AGENCY GROUND I CREWTHER GENERAL HERZOG HAUS 3602 THUN SWITZERLAND
1	MINISTRY OF DEFENCE RAFAEL ARMAMENT DEVELOPMENT AUTH M MAYSELESS PO BOX 2250 HAIFA 31021 ISRAEL
1	TNO DEFENSE RESEARCH I H PASMAN POSTBUS 6006 2600 JA DELFT THE NETHERLANDS
1	B HIRSCH TACHKEMONY ST 6 NETAMUA 42611 ISRAEL
1	DEUTSCHE AEROSPACE AG DYNAMICS SYSTEMS M HELD PO BOX 1340 D 86523 SCHROBENHAUSEN GERMANY

INTENTIONALLY LEFT BLANK.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2001	Final, January 1999–March 2001

4. TITLE AND SUBTITLE
The Lightweight Artillery Projectile

5. FUNDING NUMBERS
622618.H80

6. AUTHOR(S)
James M. Bender

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-MB
Aberdeen Proving Ground, MD 21005-5069

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2573

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report discusses the logistical advantages of using composite materials as a substitute for steel in 155-mm cargo-carrying artillery shells. A weight savings of 25–30% per projectile can be realized. Combined with the weight savings offered by the XM777 lightweight howitzer, Light and Rapid Deployment Forces can be equipped with the firepower of the 155-mm cannon utilizing projectiles with a four-to-one lethality advantage over their 105-mm counterpart, while weighing approximately twice as much. The system of lightweight howitzers and projectiles offers these forces a substantial increase in lethality as measured by kills per logistical ton.

14. SUBJECT TERMS
composite materials, artillery, logistics

15. NUMBER OF PAGES
35

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500
Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.